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Yu.V. Kurilova

ABSTRACT. The paper presents the results of a detailed analysis of the synoptic maps in the periods of the noctilucent cloud appearance in 1963-1964 over Western Siberia. The conclusion on the connection of noctilucent clouds with anticyclonic conditions, obtained before [1-5], is confirmed. The explanation of this connection, based on the account of the appearance in the troposphere and the propagation upward of the inner gravitational waves [7-9] is suggested. The formation of these waves is favored by the presence of the anticyclone. The paper gives an estimation of the possible energetic contribution from the gravitational waves into the upper layers: the energy streams appear significant. The paper compares the range of gravitation wave frequencies with the wave characteristics in noctilucent clouds with the account of the data on the general spectrum of meteorological fields, obtained recently by A.S. Monin and V.N. Kolesnikova.

The purpose of this paper is to present a detailed synoptic analysis /101* of the cases of the appearance of noctilucent clouds in 1963-1964 over Western Siberia, which have already been discussed in an article by N.P. Fast. Analysis of these data has a definite value, since up to this time little attention has been devoted to meteorological investigations of noctilucent clouds over Siberia.

To the investigation of noctilucent clouds in conjunction with meteorological conditions, a series of articles [1-4] is devoted. These articles are based upon observational material which has been compiled from 1936 to the International Geophysical Year, 1957.

The main conclusion obtained from the analysis of approximately 250 appearances of noctilucent clouds is that during the days which directly precede the appearance of the noctilucent clouds there is an acceleration in the general motion of the earthbound anticyclone in the direction of the region of projection of the noctilucent clouds. In references [1-4] data are given which show that during a twenty-four hour period prior to the appearance of the noctilucent clouds, the speed of displacement velocity of any one isobar increased greatly, attaining 1500-1800 km in twenty-four hours. Analogous deductions were obtained by Ch. I. Willman [5].

Reference [6], based upon the data of 180 cases of the appearance of noctilucent clouds over a ten year period, confirms the connection between them and an anticyclonic comb at the level of 500 mb. Such combs are mas-

*) Numbers in margin indicate pagination in foreign text.

sive formations of global size, oriented toward the pole from either the Pacific Ocean or the Atlantic Ocean or Tibet. Therefore, the anticyclones with which the appearance of the noctilucent clouds is connected are probably long and mainly massive formations.

The other peculiar conditions of the appearance of the noctilucent clouds which is noted in references [1-4] is the higher temperature. This can be explained by the fact that the noctilucent clouds are observed only during the warm summer season. In addition to this factor, the most frequent appearances of the noctilucent clouds occur during the years with a warm spring [2].

Under the conditions of the warm anticyclones, a higher moisture content is, of course, noted. Particularly in large size combs with an intensified meridional displacement there is a great tendency for a transfer of water vapor to higher altitudes.

In summation, it should be noted that all the discussed deductions are based on a great deal of factual material and, in this respect, can be considered dependable.

Let us now turn to an actual discussion of the cases of the appearance of noctilucent clouds over Siberia which have been investigated by N.P. Fast.

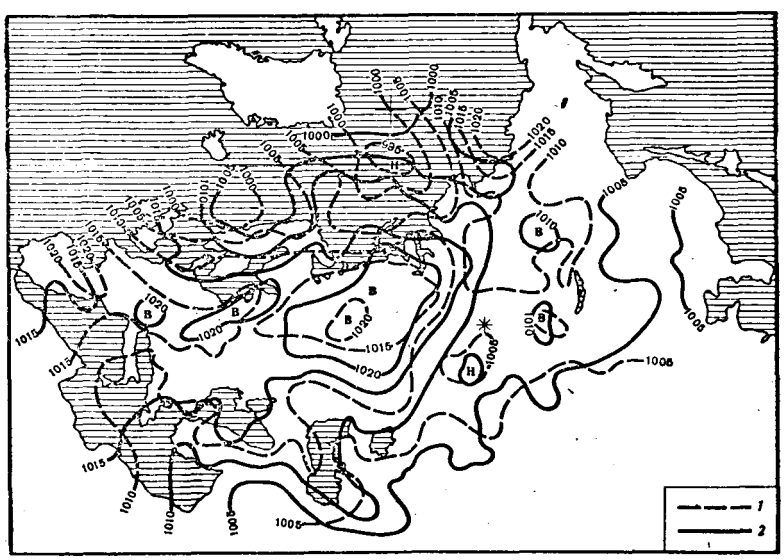

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Fig.1. Changes in the basic field during a twenty-four hour period, prior to the appearance of the noctilucent clouds (*- Tomsk) 1 - 7/12/1964, 3:00 AM; 2 - 7/13/1964, 3:00 AM

The study of the basic field during the days when the noctilucent clouds appeared was conducted with the help of synoptic maps of Eurasia. This differs greatly from N.P. Fast who actually analyzed the barograms in the point of observation.

Our method of investigation was adopted because the formation of clouds at such high altitudes must be connected with the large scale atmospheric perturbations which reflect the aerosynoptic processes for a large area.

The investigation of the synoptic maps showed that in the region of Tomsk and Novorosiysk in 1964 the cyclonic activities predominated. Nevertheless, simultaneously in the regions situated somewhat to the north and to the northwest onto which the projection of the noctilucent clouds probably fall, there were anticyclone fields. The pressure here for this summer season fluctuated between 1000 and 1020 millibars instead of the 982-995 mb for Tomsk pointed out by N.P. Fast.

Let us investigate the meteorological conditions relating to the appearance of the noctilucent clouds of different intensity, ranging from bright to dark.

Typical for all four cases of intense and dark noctilucent clouds is the rearrangement of the pressure field shown in Fig. 1. Above the northern part of Western Siberia, where the projections of the noctilucent clouds are situated, the anticyclone comb determined by the main massive anticyclone over the ETS is found. During the twenty-four hour period, an intensified growth of pressure above the zone of the projection of the clouds under observation. In the remaining cases of the appearance of the bright noctilucent clouds (June 20, 1963, June 19 and July 25, 1964) analogous transformations were observed with an apparent increase in pressure (5-10 mb during a 24-hr period) and certain changes in the orientation of the combs.

Now let us turn to the tine cases of appearance of the noctilucent clouds of medium intensity which are also connected with anticyclone combs, even though with the smaller ones. During these days the anticyclones were oriented toward the region of central Siberia (near Tomsk) from the south of Lake Aral and Lake Balkhash or from west of Sverdlovsk. For this group of noctilucent clouds of medium intensity a smaller pressure increment is noticed; 2-5 mb in 24 hours. /103

As far as the noctilucent clouds of weak intensity are concerned, their appearance relates essentially to the movement or enlargement of the comb with a pressure increase of 2-10 mb in 24 hours. Nevertheless, in individual cases the weakening of the anticyclone has been noted, which was accompanied by constant pressure or even a certain lowering of it.

The detailed analysis of sinoptic maps for cases of noctilucent cloud appearances in Siberia in 1963-1964 has shown that the intensive noctilucent clouds are connected with clearly delineated deep anticyclone and its displacement accompanied by perceptible pressure increase. Clouds of medium or weaker intensities are also connected with anticyclones, but are not as massive and are sometimes attenuated with a weakening one.

In what follows we shall discuss the formation and vertical dispersion of gravitational waves as one of the mechanisms which explain the effect of anticyclone combs on the formation of noctilucent clouds.

Hines [7] showed that irregularities of the ionosphere can be interpreted in terms of internal gravitational waves.

The parameters of these waves later obtained by Gossard [8] showed good correlation to the perturbations (according to meteor and rocket calculations) of the electronic concentration.

Hines [7] also believes that internal gravitational waves emanating from the troposphere upward, can form waves in the noctilucent clouds.

The formation of the gravitational waves, as has been noted in [7], can occur in the regions of great energy in the lower troposphere. The gravitational waves are observed in connection with stable layer in the lower troposphere with a sharp decrease of density in it and almost adiabatic distribution of the temperature above and below.

As is well known, the development of such stable inversion layers coincides particularly with anticyclone conditions. Besides, anticyclones are the regions of maximum internal and potential energy.

On the other hand, the presence of a massive anticyclone comb which violates the zonality can create, as pointed out in [9], favorable conditions for zonal assymetric heating, connected with the assymetric distribution of clouds and the great effect of the clouds on the radiation balance of the atmosphere.

Therefore, taking the above into consideration, the presence of the anticyclone can be counted as favorable to the appearance of internal gravitational waves.

For the evaluation of the possible energy inputs from the gravitational waves into upper layers, let us use the spectral curves of energy density and spectra of vertical streams of energy constructed by Gossard [8].

The vertical flow of energy in the range of the gravitational waves with a period from 7.5 min. to 2 hrs. (0.5 - 10 vibrations/hr.) can attain 1000 erg/cm^2 · sec, which is commensurable with the energy disspiation in a single column (4500 erg/cm^2 · sec) and exceeds greatly the energy flows connected with the frontal systems (50-100 erg/cm^2 · sec). As we can see, the energy flows of the gravitational waves are considerable.

Let us compare the frequency range of the gravitational waves [8] with the dimensions of the waves in the noctilucent clouds obtained in [4].

Starting with the wavelength, the combs at 5-10 km with the phase velocity of the waves of 10-30 m/sec, we can obtain the limits of the perturbation frequencies in the noctilucent clouds from 2 to 20 vibrations per hour.

This correlation can be used as an indirect proof of the relationship between the inner tropospheric gravitational waves and the noctilucent clouds.

Let us discuss the relationship to the general spectrum of the meteor-

ological fields, recently obtained by A.S. Monin and V.N. Kolesnikova [10] of the wave frequency intervals, measured in the noctilucent clouds and internal gravitational waves. In accordance with different meteorological elements in reference [10] the spectrum is represented in the intervals, starting from micrometeorological scale (with a period of 10 sec) up to the general circulation scale (with a period of 10 days) which shows two maximums of spectral energy density with a minimum between them (Fig. 2). One maximum corresponds to the synoptic vibrations with a period of 4-5 days, the second is characterized by dynamic turbulence and convection with a period on the order of several minutes.

The minimum of vibrations is observed close to the 1 hr period.

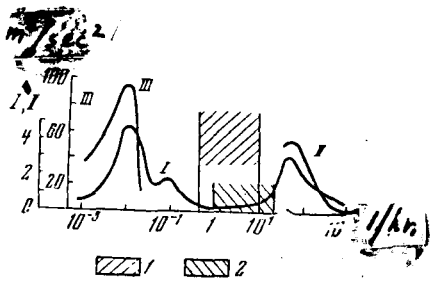

Figure 2. Spectrum of the vertical component of wind speed according to A.S. Monin and V.N. Kolesnikova.
I. According to gradient measured data.
II. According to acoustic anemomenter.
III. According to radioprobe data;
1. Range of gravitational waves,
2. Range of waves in noctilucent clouds.

The frequencies of the wave perturbations of the noctilucent clouds as well as gravitational perturbances, occur particularly during this minimum. Such correlation of the frequencies of the tropospheric energy spectrum -f the waves in the noctilucent clouds and gravitational waves proves once more the possibility of transfer of perturbations of this range from the troposphere into the upper atmosphere.

This qualitative assumption requires exact evaluation of transfer conditions of energy of the upper atmosphere depends on the vertical structure of the zonal wind, and with the velocities of the winds blowing in the western direction being less than 38m/sec.The transfer of energy into the upper atmosphere is possible in this case. Such conditions of the small Westerly winds exist, most probably, during the equinox.

Such evaluations of the gravitational waves would make it possible to determine the vertical structure of the wind, at which the transfer of these waves upward is possible, and correlate these conditions with the sporadic appearance of the noctilucent clouds. In this respect the weak (10-20 m/sec) Easterly winds at altitudes up to 40-50 km observable during certain summer days, according to rocket observation [11] are very promising. During these days in the summer conditions are probably sporadically created which are favorable for the propagation of the upward gravitational waves, similar to the situations during weak Westerly winds in the mezosphere during the period of equinox, conditions are created for the transfer of the planetary waves upward.

At the same time, such Easterly winds, by analogy with the mechanisms of spring rearrangement of the altitudinal baric fields, can be connected with the planetary comb, which is also proven by the increase in the meridional component during these days with a small zonal component of the wind in the ionosphere.

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